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FINAL REPORT

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contract # N00014-87-C-0875

SEALINK

a multi-channel telemetry system
to monitor divers

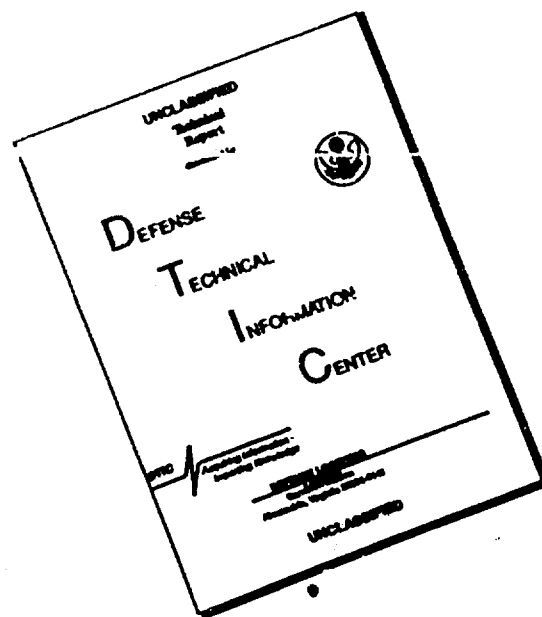
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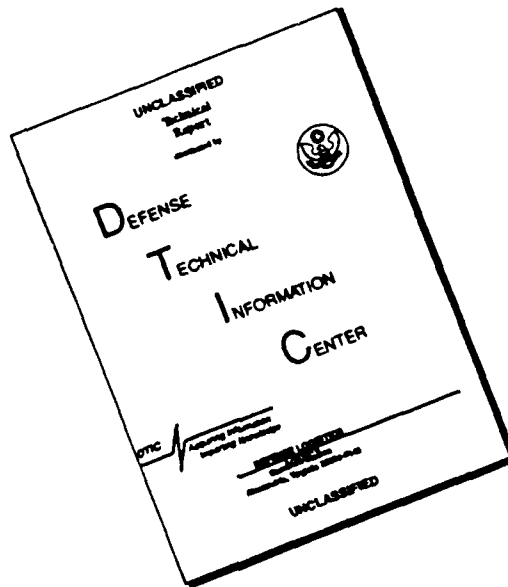
13. ABSTRACT (Maximum 200 words)

UFI has completed the design, fabrication, and evaluation of a prototype underwater physiological data acquisition and data telemetry system. The system monitors Heart Rate, Respiratory Rate, Integrated EMG (to reflect shivering), Core (Body) temperature, 4 separate skin temperatures, Ocean temperature, Ocean pressure (diver depth), and telemetry system battery status from a freely swimming diver for a period of over 11 hours. Underwater transmission range is over 1500 feet at an operational depth of over 200 feet. Wide band FSK and error correction software enables transmission of accurate information even when the data are contaminated with up to 72% errors from external noise. A floating data collection buoy receives the ultrasonically transmitted data, stores it in a nominal 10K byte cache memory and retransmits via UHF radio to a remote computer for data storage and analysis.

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May 15, 1993

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SUBJECT:
CONTRACT #N00014-87-C ---**FINAL REPORT**
"SEALINK---A MULTI-CHANNEL TELEMETRY SYSTEM
TO MONITOR DIVERS"

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CONTRACT #N00014-87-C ---**FINAL REPORT**
"SEALINK---
A MULTI-CHANNEL TELEMETRY SYSTEM TO MONITOR DIVERS"

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FINAL REPORT

"SEALINK---

A MULTI-CHANNEL TELEMETRY SYSTEM TO MONITOR DIVERS"

SUMMARY:

The purpose of this contract was to evaluate the **feasibility and methods** which could be used to reliably transmit multiple channels of physiological data from a freely swimming diver in the open ocean.

As a result of this effort, UFI has completed the design, fabrication, and evaluation of a **prototype** underwater, physiological data acquisition and data telemetry system which meets or exceeds the initial target specifications originally set forth in this contract.

Table 1 presents a comparison of the proposed and final specifications of PHASE I of this project.

- Channel capacity has been increased by 37.5%.
- Underwater range has been increased by 50%.
- Data storage backup capability has been provided at every major system interface.
- The SEALINK underwater component (diver telemetry package) is fabricated in a rugged, aluminum housing which meets the requirement for operating at 200 to 300 foot depths. Caps, fitted with internal "O" ring seals on both ends of the cannister, can be rapidly secured with cam-operated levers.

The work which UFI actually performed under this contract is far in excess of that covered by the contractual funding. The tangible results of these efforts, however, have paid off many times over in actual commercial products, some of which are now being exported to Europe, and Scandinavia. Some of these products are:

- **PneumoTrace®** waterproof respiration transducer used in Sweden to monitor patients undergoing treatment while immersed in a lithotripter tank. Hundreds of additional units have been sold in the US, Germany and other European countries for monitoring patients undergoing sleep studies
- **HOMER ---** Bedside multi channel digital data acquisition system for medical and physiological research
- **BIOLOG®** --Family of ambulatory digital data loggers for medical, psychological, and physiological research. The latest version now being constructed for NASA is scheduled to fly on the space shuttle in NOV. 1993.

TABLE 1-SEALINK PHASE I SPECIFICATIONS

<u>PARAMETER</u>	<u>PROPOSED</u>	<u>FINAL</u>
SIZE	NO SPEC	5.5" od x 24" long
WEIGHT	NO SPEC	15 lbs. Negative Buoyancy
OPERATING TIME	12 HOURS	11.5+ HOURS
CHANNELS	8 Heart rate Resp. Rate Integrated EMG 4 mixed skin temps Core Temp Ocean Temp Battery Status SPARE	11 Heart Rate Resp. Rate Integrated EMG 4 sep. skin temps Core Temp Ocean Temp Ocean Pressure Battery Status
OPERATING RANGE:		
UNDERWATER	1000 FT	+1500 FT
RADIO LINK	2 MILES	UP TO 30 miles (depending on antenna)
OPERATING DEPTH	25-50 ft	200 ft. +
DATA RELAY STORAGE CAP.	16 K	10 K (EXPANDABLE)
ULTRASONIC TELEMETRY:		
BAUD RATE	100	37.5
OPERATING FREQ.	30 KHz.	15/19 KHz
MODULATION	AM	wide band FSK
RADIO LINK BAUD RATE	300	300
DATA UPDATE RATE	1 / minute	1 / minute

OVERVIEW

SEALINK PHASE I PROJECT TASKS COMPLETED:

1. Designed, fabricated, and tested:

- 11 channel physiological data acquisition package, with microprocessor control.
- Frequency shift keyed, ultrasonic, underwater data communication system
- Physiological data simulator
- Underwater housing for diver telemetry package -- capable of operating at 200' depths
- Waterproof respiration transducer
- Microprocessor controlled data relay package with backup cache memory
- Printed circuit boards for diver telemetry package

2. Developed and tested software for:

- Separate microprocessor controlled operating systems for diver telemetry and data relay packages
- Error correction technique which can successfully recover data when contaminated with as much as **72% error**
- Data storage and display at host computer

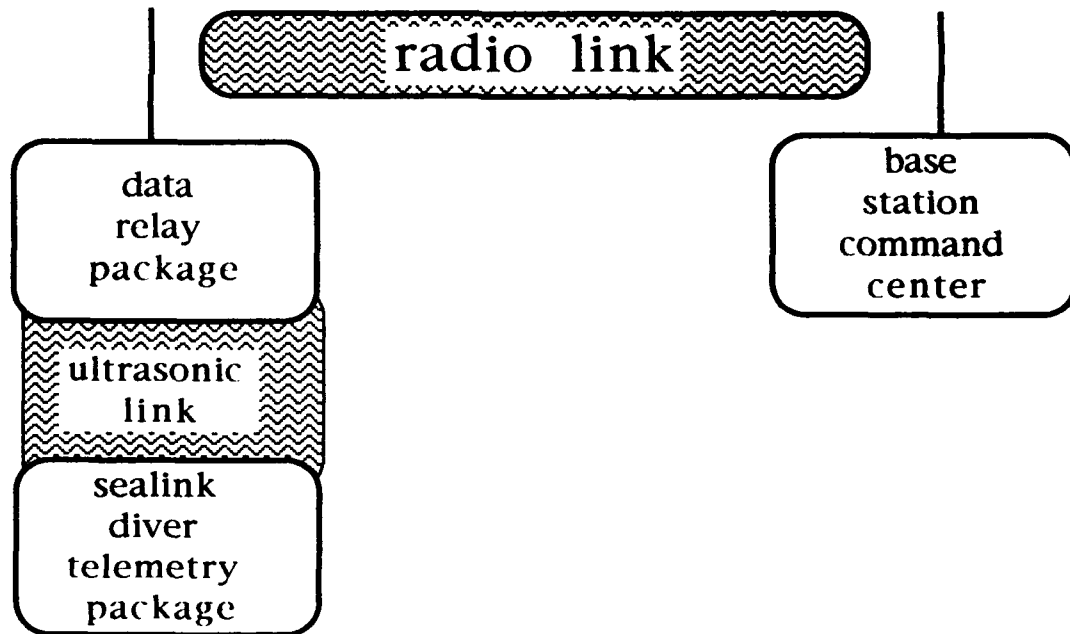
The SEALINK system has been deployed for tests on a routine basis in the main channel of the bay at Morro Bay, CA. under varying conditions of tidal flow and boat traffic. Additional tests have been held in the fresh water pool at Morro Bay High School and in a large, local, fresh water lake (Lake Lopez).

The SEALINK underwater data transmission system (with its associated error correcting software) appears to perform with a high degree of reliability, even under "worst case" noise conditions originating from boats, tidal flow, and/or "sea critters." Data has been successfully recovered in the presence of 72% errors (!) at ranges up to 500 yards. From these test results, it is not unreasonable to expect that the system could perform well at ranges of 1000 yards or more in the open sea.

The radio system has performed well at distances of 1 mile or better, with the existing 1/4 wave stub antennas. Improved range..(up to 30 miles) can reasonably be expected with larger antennas having a greater gain factor.

SYSTEM DESCRIPTION

The SEALINK Phase I system consists of three separate, but inter-related, instrumentation groups as shown below:



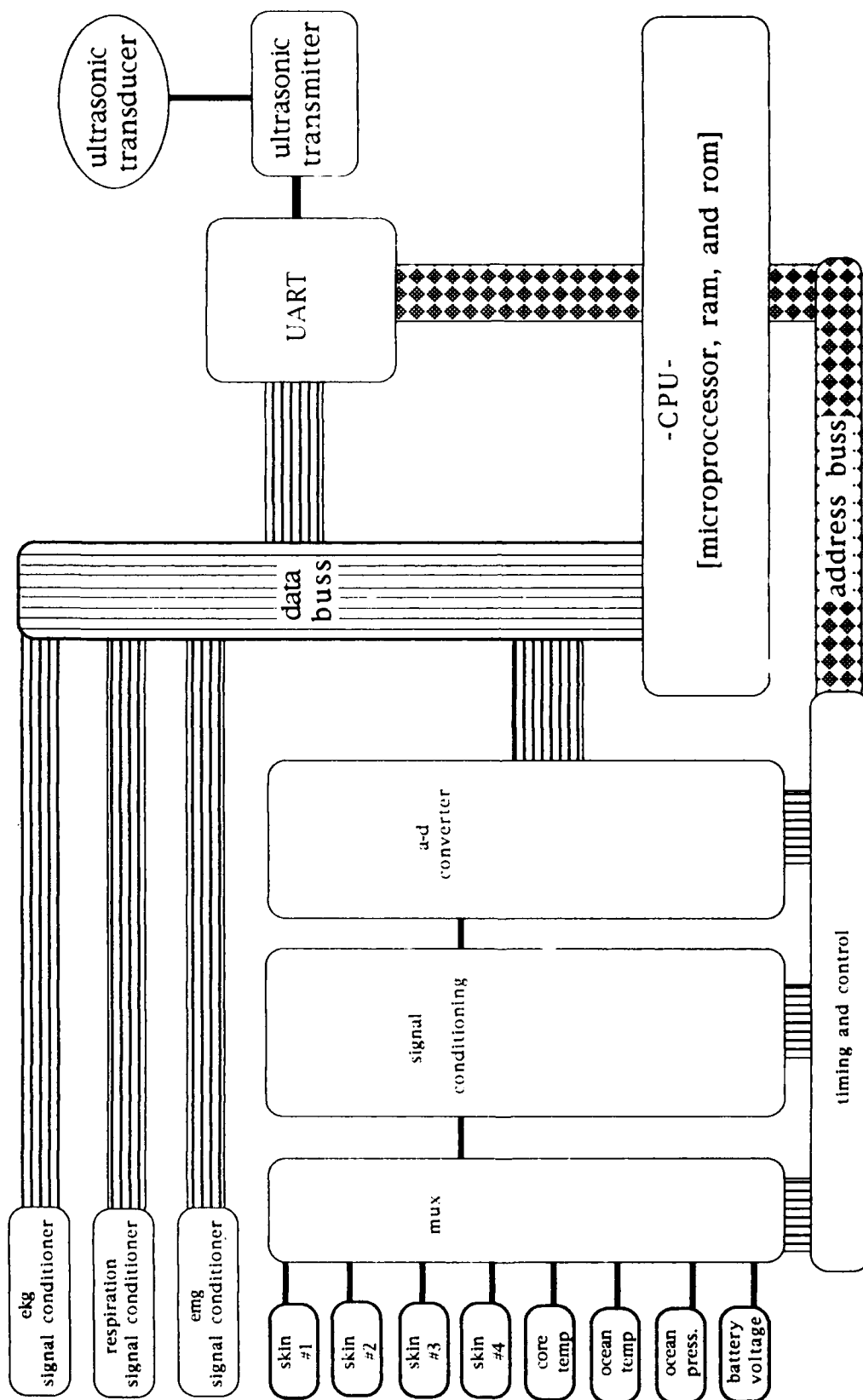
SEALINK PHASE I OVERALL SYSTEM BLOCK DIAGRAM

Diver telemetry package.... acquires and pre-conditions the data of interest, converts it to digital form, stores this information in an 8 Kbyte scratch-pad memory on the diver, configures the digital data into a format which is compatible with the error detection/correction program, and transmits this data, repeated 4 times a minute, on a wide-band, frequency shift keyed (FSK) ultrasonic transmitter.

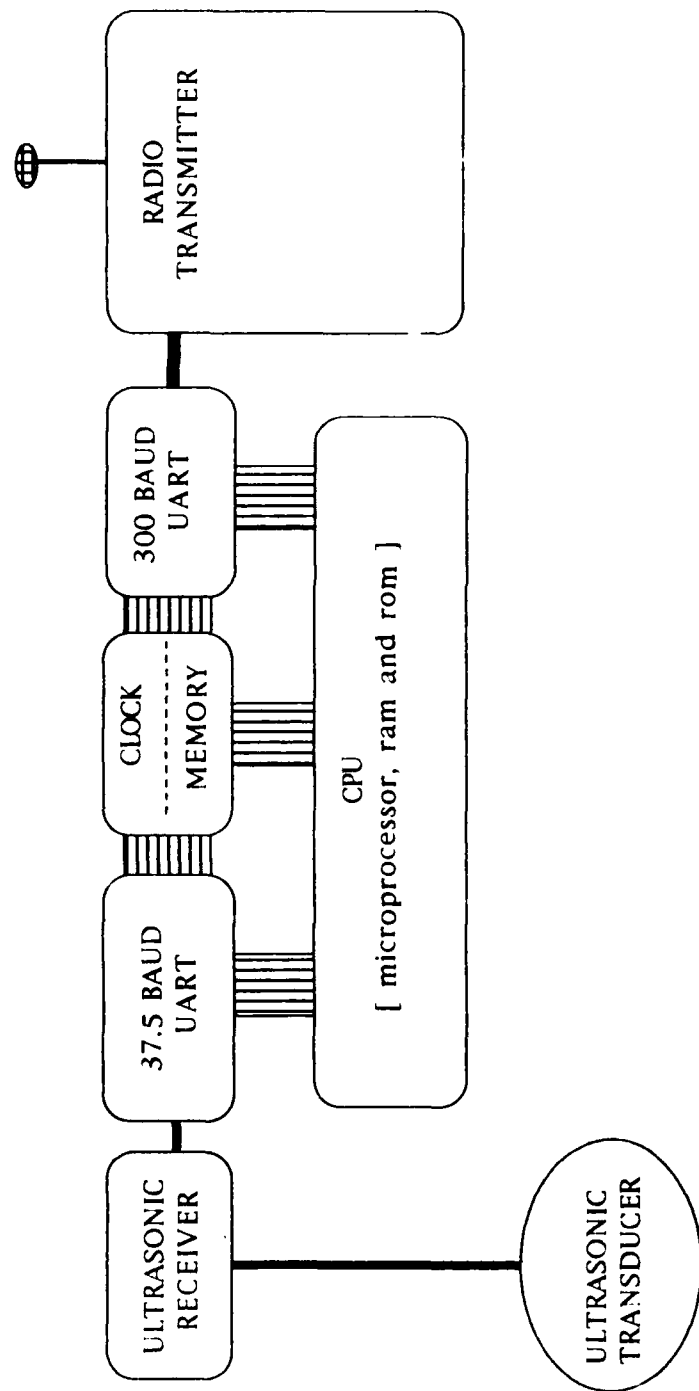
Data relay package ... receives the ultrasonic transmissions from the diver package, demodulates these to recover the original digital data, checks data for presence of errors and corrects the data if there are errors, adds a real time header, stores the data in memory for backup, and transmits the error free data once per minute over the radio link to the base station command center.

Base station command center ... receives the 300 baud radio transmissions from the data relay package, demodulates this data in the modem, and presents it to the host computer through its serial data input port. The data is displayed on the host computer's screen, stored on disk for later analysis and may also be printed out on the computer printer.

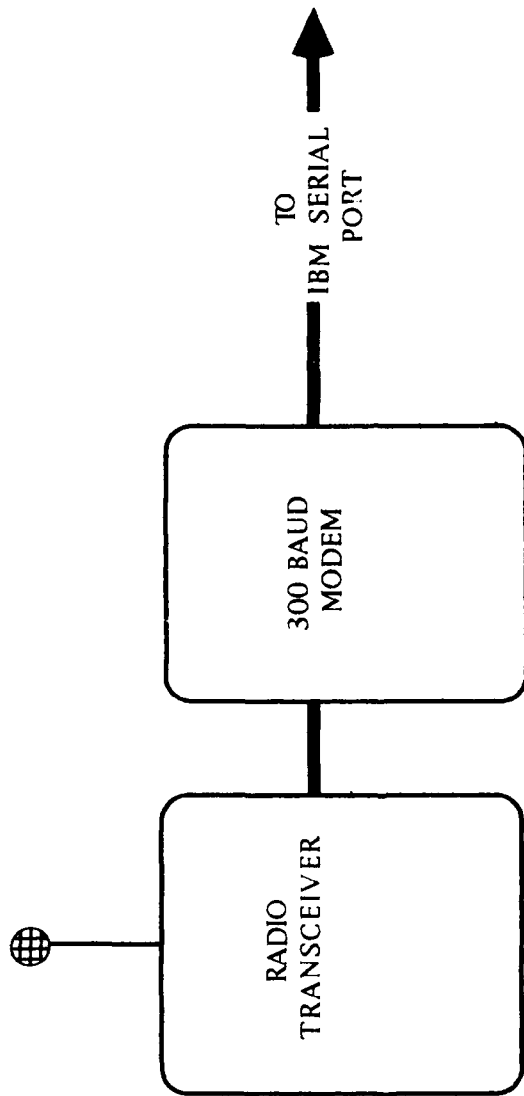
Simplified block diagrams of these individual system components follow on the next pages



SEALINK PHASE 1
DIVER TELEMETRY SYSTEM
BLOCK DIAGRAM



SEALINK PHASE I DATA RELAY PACKAGE BLOCK DIAGRAM



SEALINK PHASE I
BASE STATION COMMAND CENTER
BLOCK DIAGRAM

system design considerations

1. Packaging

The following factors dictated that the optimum configuration for the diver package should be a cylindrical cannister much like an air tank:

- a. Resistance to pressure at maximum target depths
- b. Cylindrical form factor of available battery packages
- c. Ease of mounting on diver--nestled in with existing air tanks
- d. Minimal additional resistance to diver when swimming or working
- e. Serviceability
- f. Ease of assembly and deployment on diver
- g. Long term reliability ---- leak resistance
- h. Cost of fabrication

2. Data transmission

The following factors affected the design of the SeaLink data transmission system:

- a. Desired transmission distance
- b. Desired data transmission rates
- c. Sources of interference and errors
- d. Ocean attenuation and reflection characteristics
- e. Available error correction techniques
- f. Desired transmission time
- g Available "on-board" power capacity

SEALINK PHYSIOLOGICAL DATA SIMULATOR

PURPOSE: Provides accurate, simulated physiological signals at the input of the Sealink system, to facilitate testing the system without requiring a live diver with electrodes and transducers .

<u>PARAMETER</u>	<u>AMPLITUDE</u>	<u>RATE</u>	<u>COMMENTS</u>
EKG	1 mV	160,80,40 BPM	
RESP	20-40 mV	20,10,5 BPM	sinusoid
EMG	0-3 mV	16 Hz.	3 ea. 1 min epochs
CORE TEMP	98.0 °F	NA	Constant Current
SKIN TEMP 1	80 ° F	NA	" "
SKIN TEMP 2	75 ° F	NA	" "
SKIN TEMP 3	70 °F	NA	" "
SKIN TEMP 4	65 °F	NA	" "

SIMULATOR PACKAGING

The simulator unit is completely self contained in a waterproof box, with suitable connections to all of the SEALINK inputs. It is attached to the diver telemetry cannister with a velcro strap and is activated by placing a velcro secured magnet over one end of the package.

RESULTS

TYPICAL SEALINK DATA PRINTOUT

DATE 03/14/89

UFI SEALINK

314.TST

TIME	HR	RR	EMG	SKT1	SKT2	SKT3	SKT4	CORE	OT	PRES	BAT.	INTG
10:21	0080	0010	0151	19.5	26.0	30.0	35.0	37.3	19.4	030	7.23	1234
10:22	0080	0010	0151	19.5	26.5	30.0	35.0	37.3	17.0	030	7.23	1234
10:23	0080	0010	0087	19.0	26.0	30.0	01.5	36.8	17.5	031	7.23	1234
10:24	0080	0010	0151	19.0	26.0	30.0	01.5	37.1	17.5	032	7.23	1234
10:25	0080	0010	0151	19.5	27.5	30.0	01.5	37.1	16.0	033	7.23	1234
10:26	0080	0010	0087	19.5	27.5	30.0	01.5	36.1	16.0	032	7.23	1034

Ctrl E = ERASE | Ctrl D = DUMP | Ctrl PO = PRINTER ON/OFF | Ctrl C = END

This is actual data recorded from a typical SEALINK deployment. In this case the site was a large reservoir (Lopez Lake) about 30 miles from Morro Bay. The water surface conditions were very choppy. Additional interference came from two high speed drag boats, one traversing back and forth between the diver telemetry package and the data relay package. The other stayed relatively close to the data relay package, revving its engines.

The diver package was suspended approximately 12 feet below the support vessel. All transmissions were made with this vessel UNDER WAY.

10:21 diver support vessel (dsv) approximately 50 yards from data relay
10:22 dsv approximately 150 yards from data relay
10:23 dsv approximately 300 yards from data relay
10:24 dsv approximately 400 yards from data relay
10:25 dsv approximately 500 yards from data relay

Test was terminated at this time due to severe, hazardous wind conditions.

NOTES:

2. INTG is a code which indicates data integrity. 1234 means that all four data blocks were received perfectly. A "zero" indicates the data from that block was faulty. When faulty data is received, the program prints the last good data block for that position. Each data block is transmitted three times over the underwater link and then operated on by the error correction program in the data relay package.

TEST OF SYSTEM AT DAVID TAYLOR BOAT BASIN
ON MARCH 16, 1989.

A demonstration test of the SeaLink telemetry system was originally scheduled to be held in Jan. 1989. The night before we were to leave for Bethesda, a massive **salt water leak** occurred in the cannister, while the system was powered up. The leak was due to a wire being caught underneath one of the cannister O rings.

The telemetry boards were prototypes, constructed using standard wire wrap techniques. Gold plating "flew" off the IC socket terminals to re-plate any terminal energized with a positive voltage. We immediately flooded the boards with de-ionized water and then dried them out. We were amazed to find **THAT ALL OF THE CIRCUITS STILL WORKED!** But under a microscope, severe salt water corrosion was evident throughout the circuitry. We had no confidence that the system would continue to perform reliably.

Consequently, we decided to convert the Sealink circuitry to a set of printed circuit boards. This endeavor was originally planned as a Phase 2 project. It consumed a tremendous amount of money and effort---- well over \$5,000.

The system was totally rebuilt in less than one and a half months.

Obviously exasperated, (as were we) Commander Peter Kent set up a "do or die" final test of the SeaLink System to be held at the David Taylor Boat Basin test facility on the afternoon of March 16, 1989.

Prior to this time, we tested the system and then tested it again. It certainly was not our design goal to fail this test.

UFI personnel involved were Harve M. Hanish (VP of Engineering) and William J. Anderson (Software Engineer).

Thomas Doubt, Ph. D. of NMRL and Commander Kent were present.

UFI had requested that we be allowed to familiarize ourselves with the electronic environment and physical layout at the test facility to assure that there would be no disastrous interference from other tests concurrently underway in the pool.. We asked that we be allowed access to the facility either the day before or on the morning before the test.

This request, made to Cmdr. Kent, was emphatically denied!

On the morning before we left for the boat basin, we tested the system, transmitting through air.. It worked flawlessly.

We arrived at the boat basin shortly after 1300 hours. Nobody from the test facility was aware that our test was going to be conducted on that day, at that time. **THEY WERE TOTALLY UNPREPARED FOR US!** In addition, several other tests were being conducted in the pool. One involving wave generation, the other involving generation of some ultrasonic signals. The chamber, fully the size of a football field, was only dimly lit by just a few lamps in the ceiling far above us.

It took over an hour and a half to locate the proper personnel, orient ourselves and prepare to deploy the system. By this time it was approximately 1430 hrs.

We put the system in the water and checked for interference and proper performance. All of these initial tests looked very good.

Shortly after 1500 hrs. Dr. Doubt entered the water with the simulator and the cannister. It transmitted good data for 1 or 2 minutes and then the receiver signal strength indicator showed that we had a transmission problem.

We had not brought test equipment with us, thinking that we would be able to borrow scopes and such from the Navy. It took over 30 minutes for us to locate someone at the David Taylor basin who was willing to loan us a scope so we could trouble shoot the system.

By 1545 we had determined that a wire in the ultrasonic transducer cable had failed due to repeated bending stress. In probing the circuitry inside the cannister, in the very dim light, we also had broken one of the #30 gauge wires from the ultrasonic driver electronics to the transducer connector. We were quite willing to repair these problems, but it would have taken several hours, since waterproof connectors had to be re-encapsulated and this has a finite cure time.

Cmdr. Kent said that his workday ended at 1600 hours and that he would not be available for any further tests—— ever.

He also stated that while he believed that the system worked, he had no faith in our ability to build reliable equipment that worked. Needless to say, we were crushed. **The object of this Phase 1 contract was not to build reliable equipment---it was to evaluate methods and feasibility.**

We returned to our hotel, obtained the necessary materials to repair the broken wires, and in several hours we were back on the air --working perfectly.

Unfortunately, we had no cognizant authority (then or ever again) to whom we could demonstrate this.

While UFI lost the possibility of PHASE 2 funding to continue this project, we feel the Navy lost a great deal more.

It is indeed unfortunate that one individual with the operant philosophy of a grade school principal was allowed to oversee this project.

The outcome of the Sealink project could have been very different if Cmdr. Kent had exercised only a little patience and common courtesy. This would not have cost the Navy one additional cent.

As you can see, much of the technology "fall-out" from the Sealink endeavor has achieved the goals for which the SBIR program was originally designed. For these, we are thankful.

CONCLUSIONS

This project has shown that it is feasible (albeit difficult) to transmit multiple channels of physiological data from a freely swimming diver.

Problems---

1. Power required to reliably transmit ultrasonic data from diver for required distance and duration
2. Sources and intensity of interference
3. Error correction methods required to combat interference which slow down data throughput
4. Connector and cable reliability under the stresses to which exposed
5. Deployment---time it takes to properly instrument the diver ..
6. Possibility of operational failure of the cannister dictates that dry nitrogen PRESSURIZATION techniques should be used to indicate presence of leaks.

FUTURE OBJECTIVES

We list below, not in any order of priority, some of the objectives which we feel would need to be addressed in a Sealink Phase II effort:

- Simplify diver instrumentation harness
- Improve reliability of input connectors
- Improve the ultrasonic link to achieve higher data throughput, greater range, with less power consumption
- Evaluate SEALINK's operational performance and reliability and improve where required
- Expand the backup memory in the data relay package
- Implement 6 diver system -- This increases the software and hardware complexity by several orders of magnitude. The ultrasonic link would have to be expanded to allow two way communication. and control of the entire system from the data relay package
- Explore methods to reduce size, increase performance, and reduce power consumption
- Implement data encryption techniques

However, most of these tasks would be obviated if our following recommendations are implemented.

RECOMMENDATIONS

1. Unless there are strident, urgent needs for the immediacy of real time data monitoring in this milieu, physiological data acquisition can be more easily accomplished with much less cost and with many magnitudes of improved system reliability by using an ambulatory digital data recorder instead of real time telemetry. Such a recorder (model 3992/1 BioLog®) is shown in the appendix which follows.

Assuming that the current channel throughput capacity of the SeaLink telemetry system is 100 Bytes per minute, an ambulatory recorder with a 1 Mb. Ram Card would allow storage of over one thousand times this data capacity. Such an ambulatory data logging system could realistically be contained in an enclosure measuring less than 1/10 the volume of the existing Sealink package.

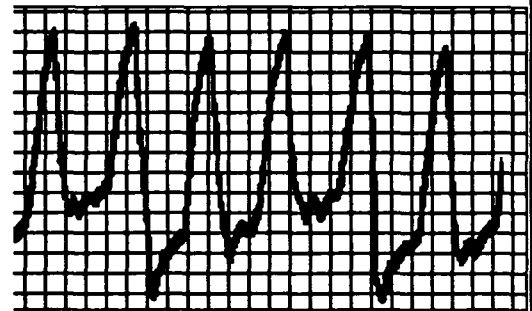
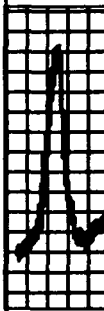
After development (primarily packaging), a complete SeaLink type BioLog® system could probably be manufactured to sell for less than \$15,000.

2. Software controlled alarm thresholds could also easily be included. Such a unit could then have two functions –research data acquisition and safety through warning/alerting of supervisory personnel as well as the diver.
3. Additionally, the requirement to implement data encryption techniques into the system would be eliminated, since all data would be stored "on board" the diver; it is extremely difficult to eavesdrop on a Ram Card.

model 1130
PNEUMOTRACE®
respiration transducer



*"an innovative solution to
the often difficult problem
of recording respiration
over long time periods"*



patent applied for

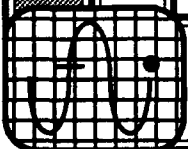
This radically new, solid state, strain gauge transducer responds linearly to changes in abdominal or thoracic circumference.

- **RUGGED** --- virtually indestructable!
- **COMFORTABLE** --- so supple and resilient
it is perfect for use with the sleeping subject
- **RELIABLE** --- measures **TOTAL** circumference ---
not just one small segment of the chest
- **ADAPTABLE** --- **easily connected**
to ANY polygraph, impedance pneumograph or strip chart recorder
- **ECONOMICAL** --- replaces the bulky bellows/pressure transducer
combination, while saving hundreds of dollars

SPECIFICATIONS

- **SIZE**-----2" wide x 0.125" thick x adjustable length
(Regular size will accomodate circumferences of 12" to over 100".
special sizes also available)
- **RESISTANCE**---200 ohms (units may vary +/- 50 ohms)
- **WIRE LENGTH**--6' nominal--can be 50 feet or more without degradation
of performance
- **CONNECT.** as required
- **WASHABLE**

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**model 3992 BIOLOG® ambulatory data recording system
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We call our new BioLog® "ARNOLD"
because it has a real attitude problem—

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Hunts down the data you want —
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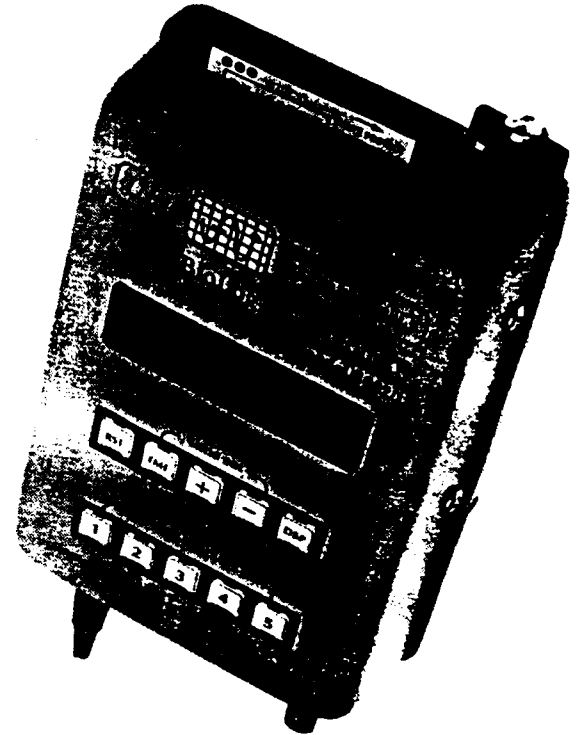
Holds on to the recorded data
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Designed and constructed by UFI
to yield years of faithful service.

• **ADAPTABLE** —

Considerate design allows us to modify
software and hardware to meet your
changing research requirements.



— *designed by UFI at NASA's request* —

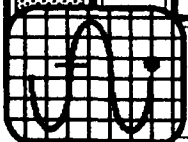
Reliably collects up to 6 channels of biological data from any ambulatory subject, in most environments, over an extended period of time.
The BioLog® assures confidence by giving you continuous feedback of both analog and digital system operation.

Inclusion of UFI's proprietary FETRODE® technology for bio-electric signals makes the BIOLOG® virtually unaffected by subject movement!

Can be configured to record:

- | | | |
|-----------------------------|--------|------------------------|
| • EGG (Electro-Gastrogram) | • ECG | • Activity |
| • IBI (Inter-beat Interval) | • GSR | • Respiration |
| • Integrated EMG | • ENG | • Snoring |
| • Pulse transit time | • Temp | • Swallowing |
| • Vocalization | | • <i>And many more</i> |

Complete systems include everything required to record and download data into your computer. Subsequent detailed analysis, using your own spreadsheet software, is easily accomplished.



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